INTELLIGENT ENERGY MANAGEMENT IN A TWO POWER-BUS VEHICLE SYSTEM

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INTELLIGENT ENERGY MANAGEMENT IN A TWO POWER-BUS VEHICLE SYSTEM

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Intelligent Vehicle Power Management

- Vehicle power management has been an active research area in recent years
- Most approaches were developed based on mathematical models, human expertise, or knowledge derived from simulation data.
- Control strategy of a military vehicle is more complicated than commercial vehicles
  - Multiple power sources
  - the complex configuration and operation modes,
  - heavy weight
  - multiple functions, which cause big load fluctuation
    - engaging weapons, turning on sensors, silent watch, etc.
- Our research: Cognitive Intelligent Vehicle Power Management
  - Intelligent power control based on machine learning, optimization and human intelligence

In this presentation

- We present our research in optimizing power flow in a vehicle power system that employs multiple power sources.
  - *focusing on a vehicle power system architecture that is used in vehicles such as Mine Resistant Ambush Protected (MRAP) vehicle*
  - *Developing algorithms for intelligent energy control*
  - *Using a commercial simulation software to model the vehicle system for experiments*
  - *Constructing a lab hardware setup to verify the energy management algorithms*

MRAP Power System Simulation, Optimization and Hardware Implementation

Building three MRAP systems

MSTV
MODELING AND SIMULATION, TESTING AND VALIDATION

- **Full scale simulation using a commercial software**
  - Using Stryker as a vehicle model
  - Constructing the power components with the same sizes as in SPEC

Simulation of Hardware MRAP system

- *Using the same sizes of power components as in hardware setup*

Hardware Implementation of MRAP

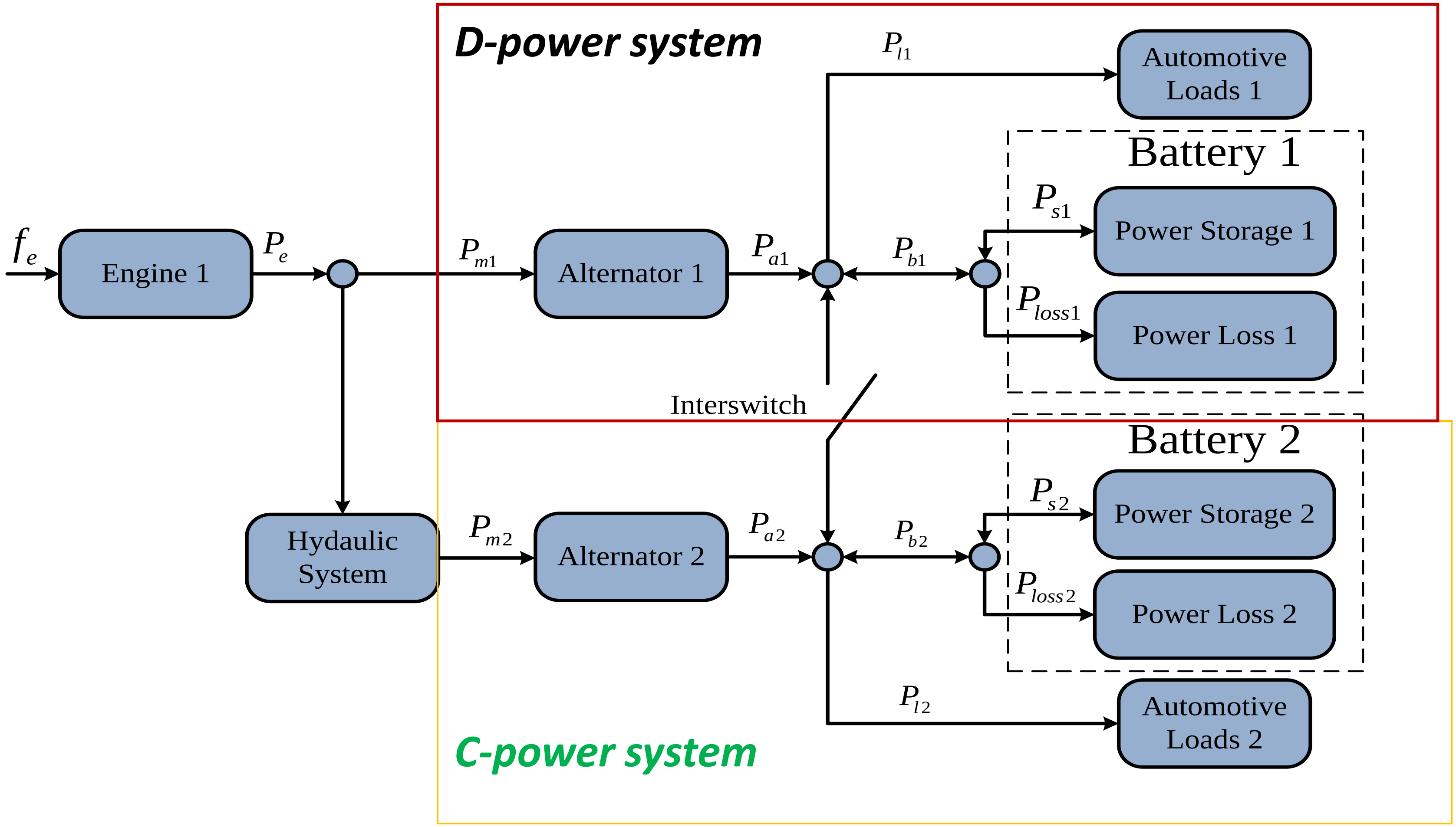
- *Scaled down version due to the available hardware*

Intelligent Power Management in a Simulated MRAP Vehicle

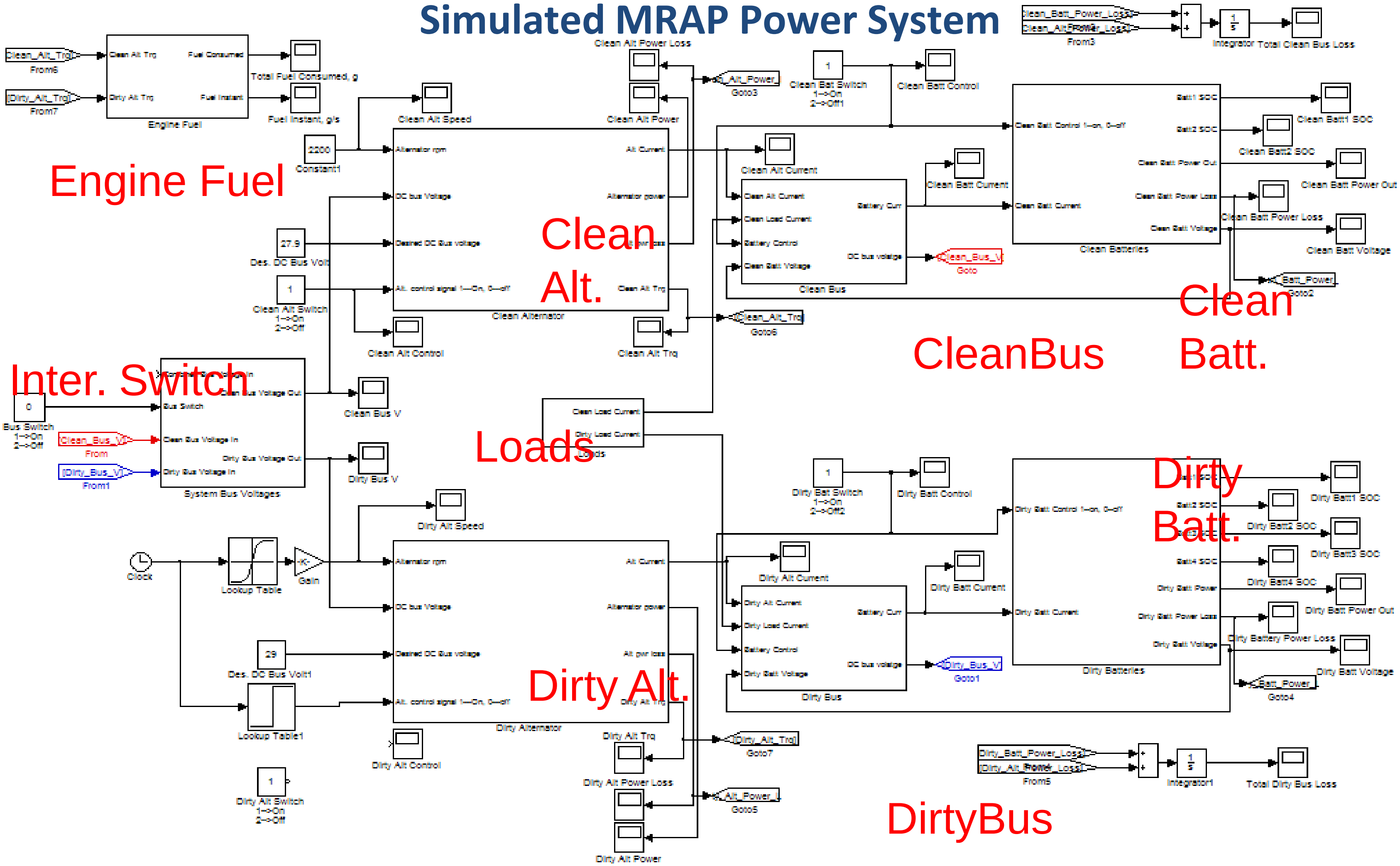
Simulation Environment

- Simulation program:
- Vehicle Model: Stryker model
- Power system:
  - Build based on specification of MRAP power system

MRAP Power System Specification



Simulated MRAP Power System



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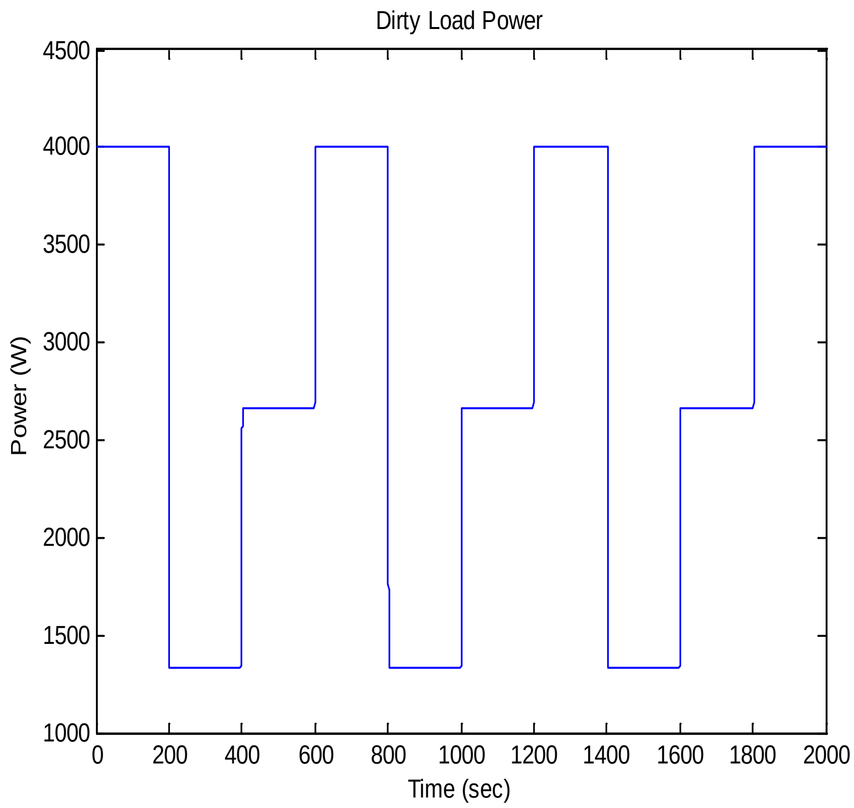
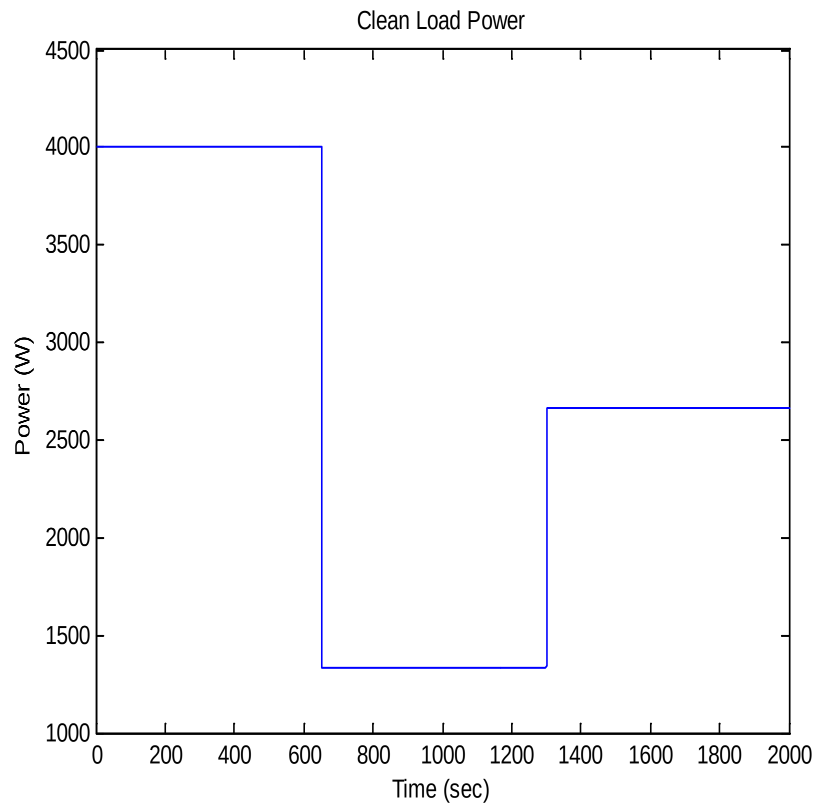
Intelligent Power Management Algorithms

- Only optimize the power to or from dirty battery, D_P_s
  - Will optimize both C_P_s and D_P_s in next phase
- Three algorithms:
  - Applying DP optimization to a given drive cycle
  - Applying optimal power setting found by DP to online controller
  - Training a neural network (NN) for online controller

Dirty and Clean Loads used in Experiments





Designed Drive Cycle

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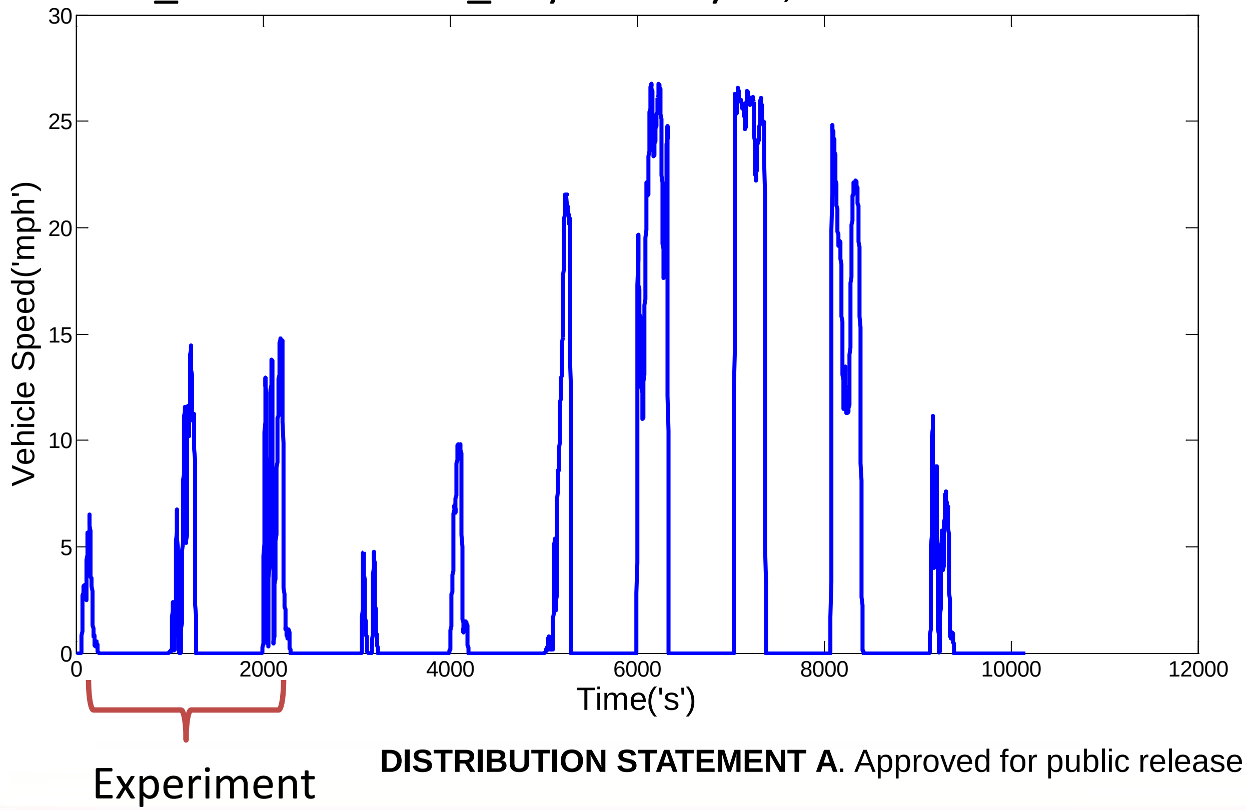
- A drive cycle in which vehicle is moving 30% of time and 70% of time is idle
  - The speed profile is constructed based on two standard drive cycles for heavy trucks
    - WVU_Inter and WVU_City drive cycle;



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Cycle Segment (sec)	Benchmark Fuel (kg)	DP Fuel (kg)	Online Fuel (kg)	Online Fuel (kg) w/ SOC Correction	DP Savings (%)	Online Open Loop DP Savings (%)
0-2000	1.6920	1.5614	1.6030	1.6100	7.72	4.8
2001-4000	1.8919	1.753	1.7585	1.7660	7.34	6.65
4001-6000	2.1115	1.9706	1.9846	1.9921	6.67	5.65

Neural Network Online Implementation

- Neural networks are trained to behave like DP, outputting optimal Ps (Dirty bus battery power).
- Online implementation contains two neural networks
  - One is trained for interstate drive cycle, another for city drive cycle
- When the vehicle is not in idle mode:
  - determine the current roadway type
  - Call the neural network trained on the current roadway type

Performances DP and NN for the first 2000 second drive cycle

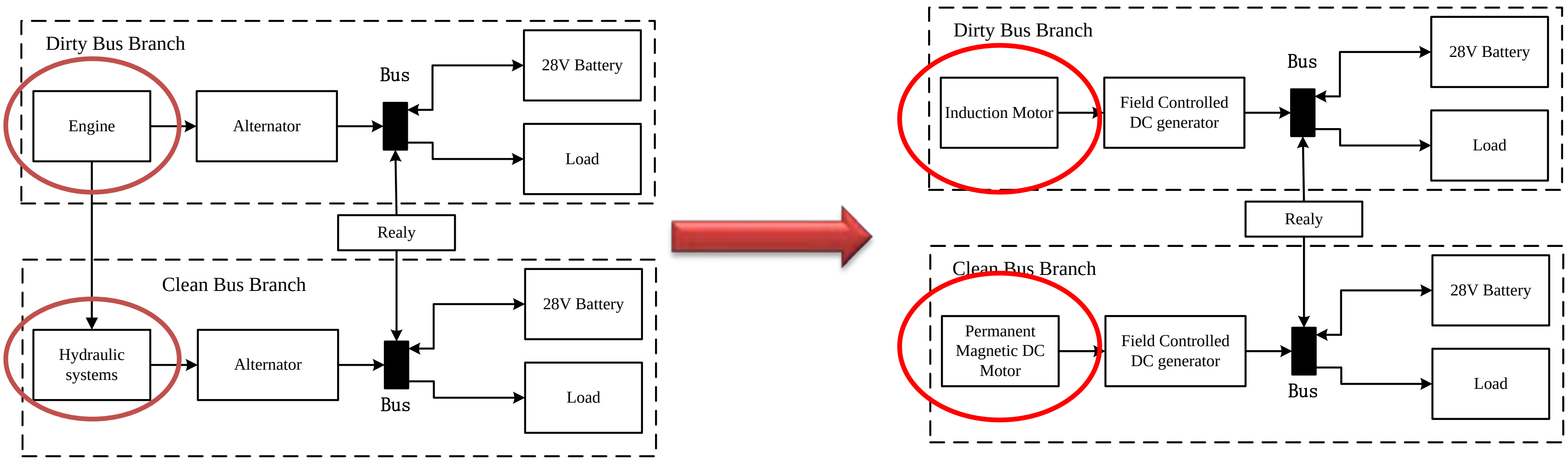
controller	Fuel Consumed (kg)	Fuel w/ SOC correction	Savings (%)
Software based controller	1.6920		
DP	1.5614		7.72
Online DP	1.6030	1.6100	4.85
Online NN	1.5961	1.6074	5.00

MRAP Power System Hardware Implementation and Experiments

Hardware Implementation of MRAP Power System

- It is a scale-down version due to the hardware components currently available at the authors' power electronics labs.
  – Using Electric Motor and Generator with a reduced ratio to replace the real MRAP engine and alternator
- Control algorithm:
  – Commercial software based control algorithm and
  – Algorithm based on DP developed by the authors

System Configuration



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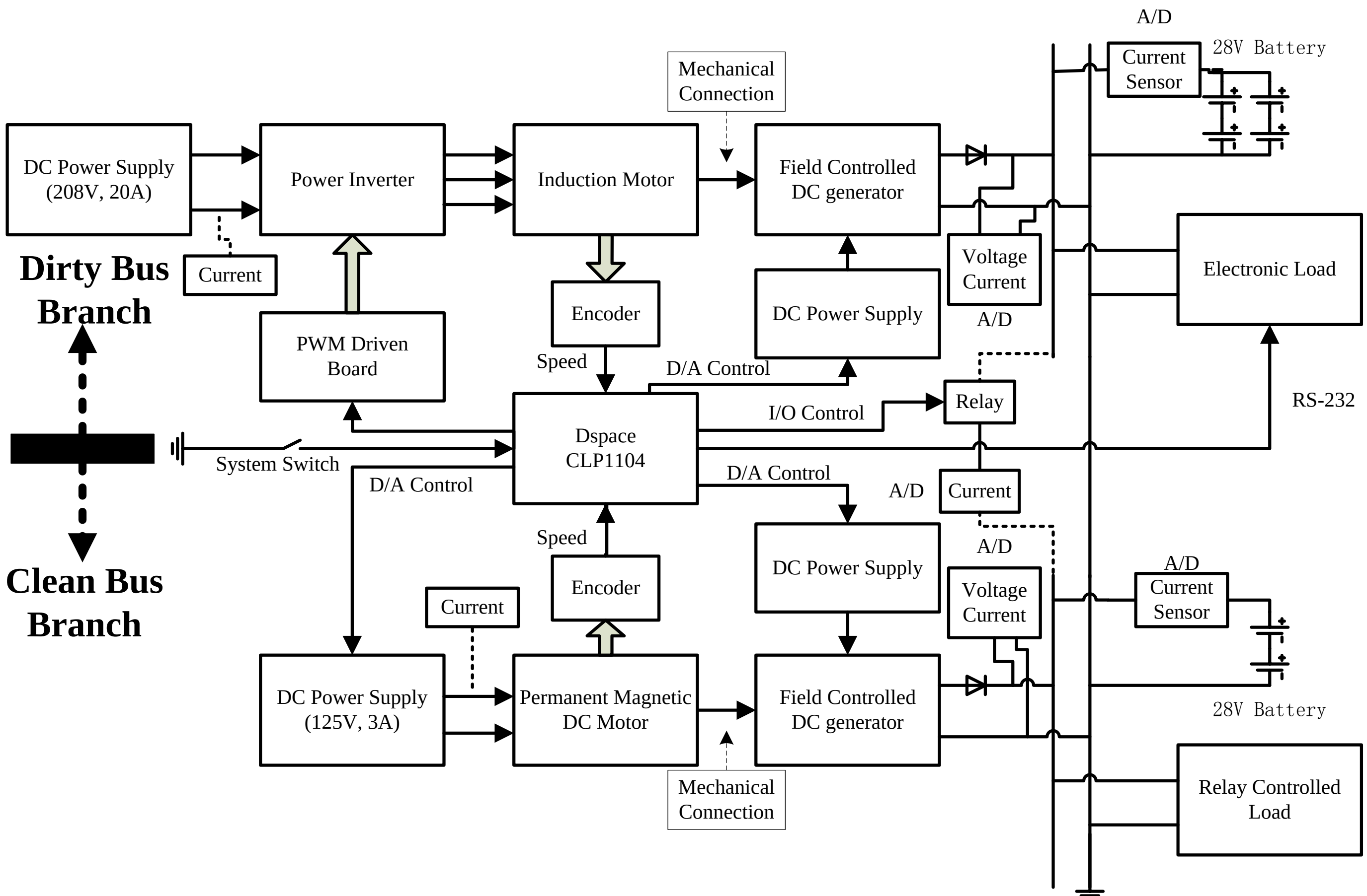
Hardware System Implementation

MSTV MODELING AND SIMULATION, TESTING AND VALIDATION



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System Components

Dirty Bus Branch

Original System	Demo System
Engine	Induction Motor
Alternator	Field Controlled DC Generator
Battery	Lithium Battery
Load	Electronic Load

Clean Bus Branch

Original System	Demo System
Hydraulic System	Permanent DC Motor
Alternator	Field Controlled DC Generator
Battery	Lithium Battery
Load	Resistance Load with Relay Control

Dirty power system

Induction Motor(Engine):

- Rated Voltage: 208v
- Rated Current:10.8A
- Rated Power: 3 H.P
- Rated Speed: 1800 rpm
- 3 phase, winding wounded rotor

Battery:

- Type: Lithium Battery
- Rated Voltage: 12.8v(per unit)
- Capacity: 40Ah(per unit)
- Total:
- Rated Voltage: 76.8v(*6)
- Capacity: 40Ah

DC Generator(Generator)

- Rated Voltage: 125v(90v)
- Rated Current: 19A
- Rated Power: 3 H.P
- Rated Speed: 1800 rpm

Power Supply

- Maximum Capacity : 600v/20A,

Inverter:

- Applied Power System Products
- Maximum Capacity : 600v/100A,
- Maximum Frequency: 20KHz

Clean power system

PM DC Motor:

- Rated Voltage: 125
- Rated Current:3.2A
- Rated Power: 1/3 H.P
- Rated Speed: 1750 rpm

Battery:

- Type: Lithium Battery
- Rated Voltage: 12.8v(per unit)
- Capacity: 40Ah(per unit)
- Total:
- Rated Voltage: 25.6v
- Capacity: 40Ah

DC Generator

- Rated Voltage: 125v
- Rated Current: 3.0A
- Rated Power: 1/3 H.P
- Rated Speed: 1800 rpm

Power Supply

- Maximum Capacity : 600v/10A

Relay:

- Maximum Current: 200A

Control Strategy

- Dirty Bus branch
  - Induction Motor: VVVF Control;
  - Generator: Field Voltage Control. Proportional Integral Control (PI) Control
- Clean Bus branch
  - PM DC Motor: Voltage Control. PI Control
  - Generator: Field Voltage Control. PI Control
- System Control Algorithm: (baseline controller)
  - Target: SOC=0.7; control target: SOC=0.7 using PI Control
  - Not allowed to exceed the maximum current of alternator.

Hardware Configuration

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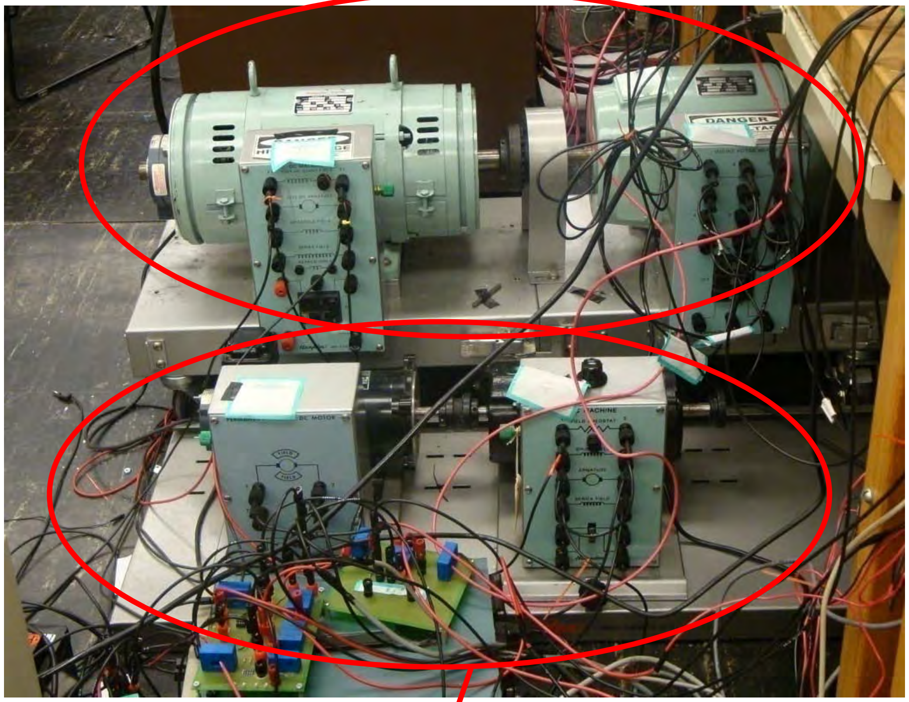
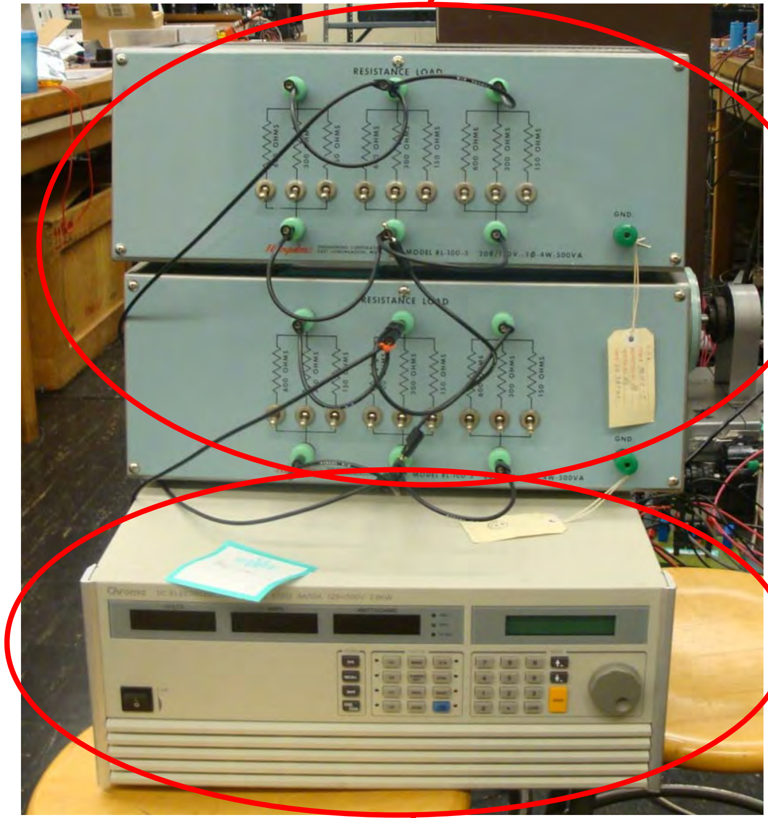
Dirty Bus Motor and Alternator



Clean Bus Motor and Alternator

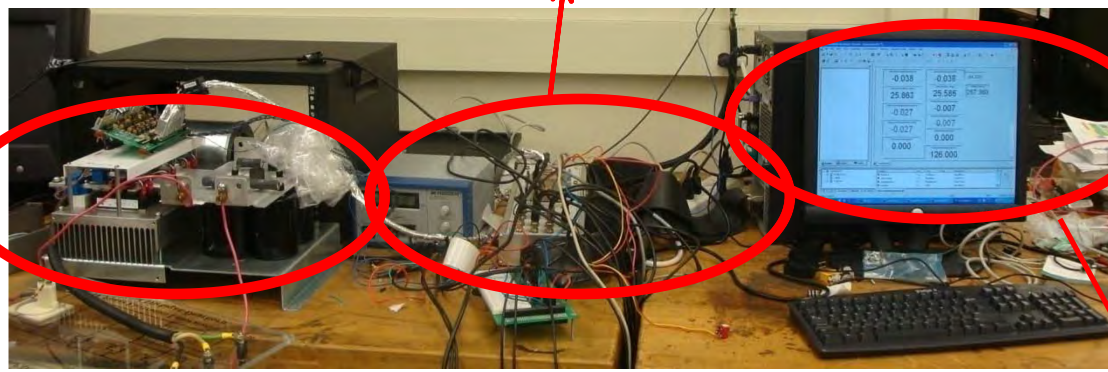
Clean Bus Load



Dirty Bus Load

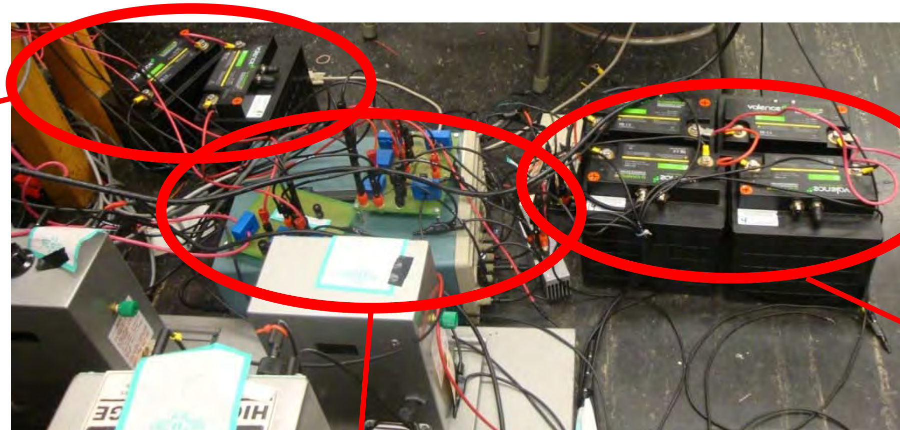
Hardware Configuration

Real time environment tool



Power Inverter

PC



Clean Bus Battery

Dirty Bus Battery

Current and Voltage Sensor

Measurable data

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Dirty Load Branches:

- Generator output current
- Battery current
- Bus Voltage
- Power supply output voltage
- Power supply output current
- Induction motor speed

Clean Load Branches:

- Battery current
- Bus voltage
- Speed of PM DC motor
- Power supply output voltage
- Power supply output current
- Generator output current

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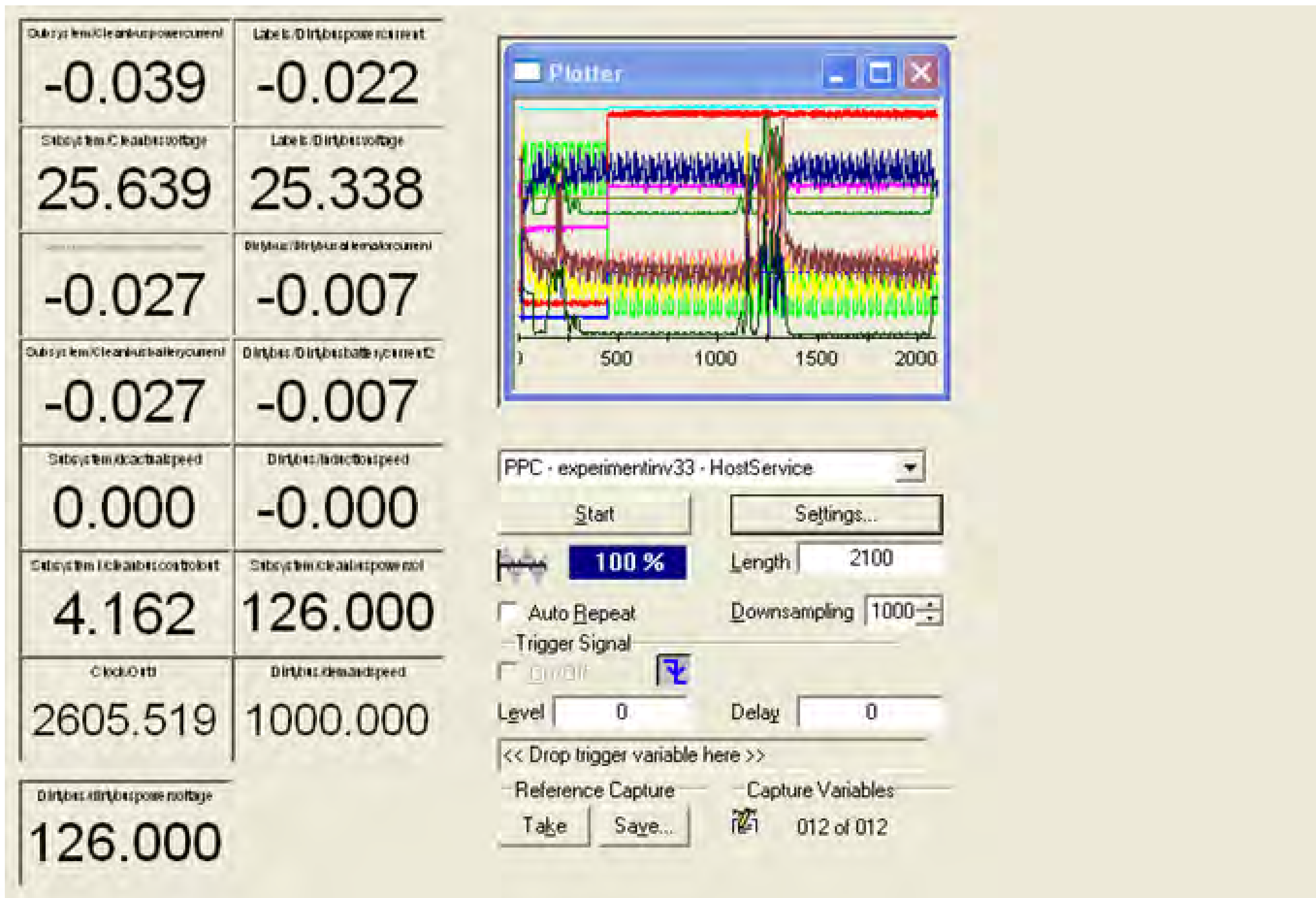
Calculated Data

- Dirty Bus Branch:
  - SOC of Battery;
  - Torque of Induction Motor;
  - Equivalent Fuel Consumption
- Clean Bus Branch:
  - SOC of Battery;
  - Torque of PMDC Motor.

Real-time Environment Data Acquisition

- Based on the real time environment tool.



Fuel Consumption

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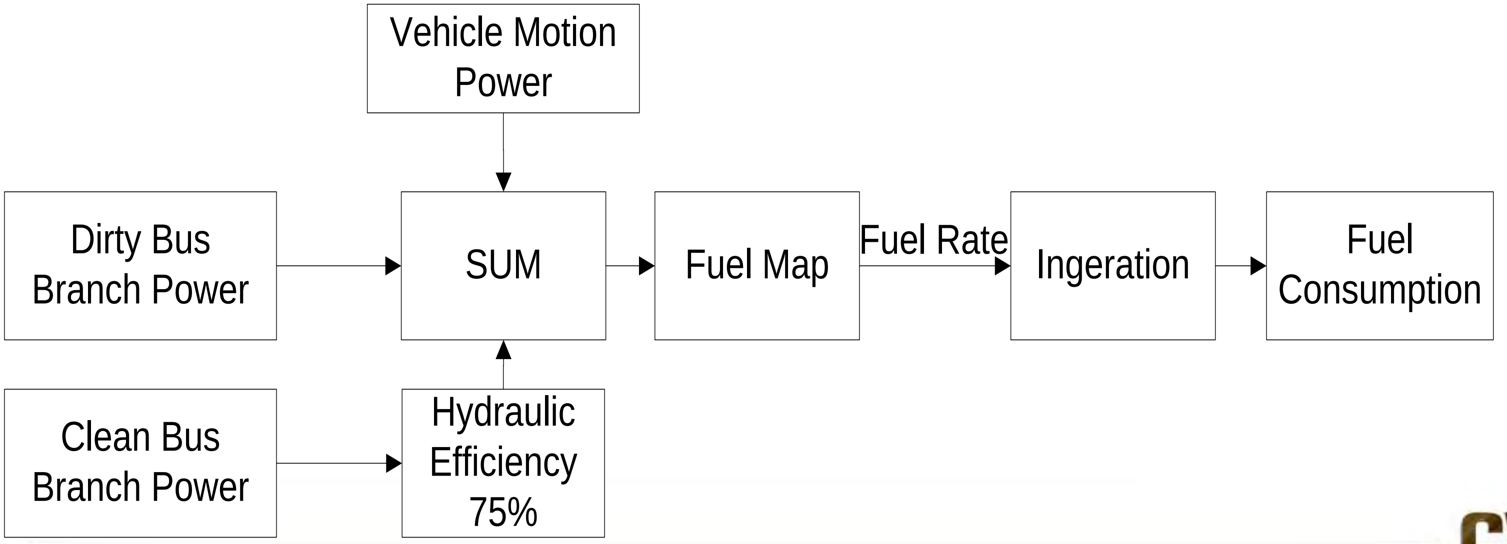
- Obtain the DC bus current
- get the power and torque of clean bus branch and dirty bus branch
- Add vehicle motion power
- Look up the engine fuel map to get the fuel consumption.
- Hydraulic system efficiency: 75%;



Designed Drive Cycle

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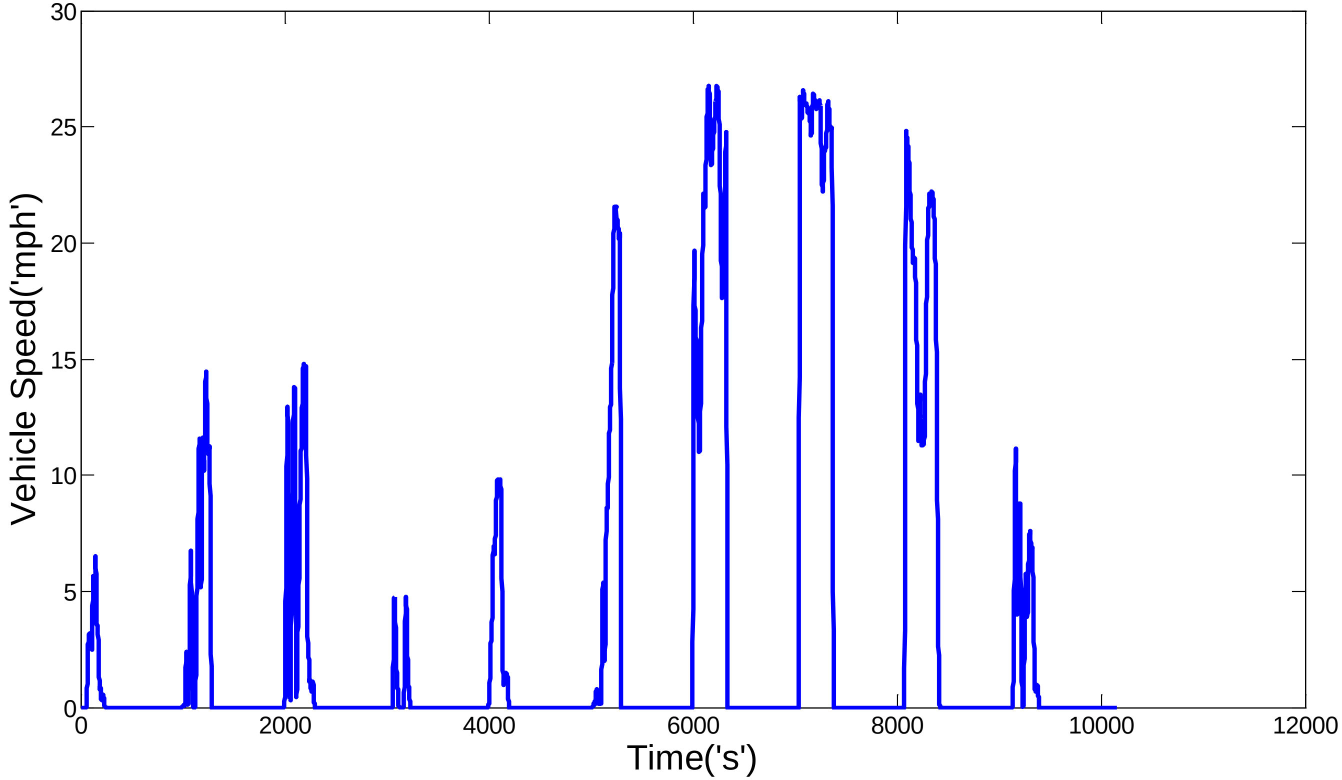
Based on the WVU_Inter and WVU_City Drive Cycle;
70% idle.



Experiment

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System Performances

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Algorithm	Fuel Consumption	Improving
Software based Control Algorithm	3.5336kg	
Dynamic Programming Control	3.352kg	5.14%
Online Dynamic Programming Control	3.419kg	3.24%

Performance Summary of Intelligent Power Controller in MRAP Power System

Simulated MRAP Power System Embedded in software Stryker Model

controller	Fuel Consumed (kg)	Fuel w/ SOC correction	Savings (%)
Software tool based controller	1.6920		
DP	1.5614		7.72
Online DP	1.6030	1.6100	4.85
Online NN	1.5961	1.6074	5.00

Hardware Implementation of MRAP Power System

Control ler	Fuel Consumption	Saving (%)
Software tool based controller	3.5336kg	
Offline Dynamic Programming	3.352kg	5.14%
Online Dynamic Programming	3.419kg	3.24%

Simulated hardware MRAP Power System

Controller	Fuel Consumption	Saving (%)
Software tool based controller	3.453kg	
Offline Dynamic Programming	3.27kg	5.51%
Online Dynamic Programming	3.336kg	3.39%

- Video demo if time permits

Conclusion

- An intelligent power controller for a two power-bus system in vehicle systems is presented.
- Based on the simulations, and experimental results implemented in the lab setup, it can be concluded that the intelligent controller developed by the authors can improve fuel consumption through online vehicular power management in a real time environment.
  - In the simulated vehicular system, this controller saved about 5% fuel.
  - In a lab setup environment, the controller saved about 3.2% fuel.
- The tools developed by the authors and reported in this paper can be used to save significant cost and development efforts by the manufacturers prior to any production level activities involving such vehicular systems.